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Title: Proof of Principle for Helmet-Mounted Display Image **Quality Tester**

Abstract: Helmet-mounted **displays** (**HMDs**) provide essential pilotage and fire control **imagery** information for pilots. To maintain system integrity and readiness, there is a need to develop an **image** quality-**testing** tool for **HMDs** . There is currently no such tool. A framework for development of an **image** quality tester for the **Integrated Helmet** and **Display Sighting System** (**IHADSS**) used in the U.S. Army's AH-64 was proposed in Hsieh et al.. This paper presents the prototype development, summarizes the bench test findings using three **IHADSS** helmet display units (HDUs) and concludes with recommendations for future directions. The prototype tester consisted of hardware (two cameras, position sensors, **image** capture/data acquisition cards, battery pack, HDU holder, moveable rack and handle, and **computer**) and software algorithms for **image** capture and **analysis** . Two cameras with different apertures were mounted in parallel on a rack facing the HDU...

...designed to allow users to position the HDU in front of the two cameras. The **HMD** test **pattern** was then captured. Sensors were used to **detect** the position of the holder and whether the HDU was angled correctly in relation to the camera. Two sets of unified algorithms were designed to **detect image** features presented by the two cameras. These features included **focus** , orientation, displacement, **field -of- view** (FOV), and number of **gray** -shades. **Images** of test **patterns** were captured, **analyzed** and used to develop a specification for each inspection feature. **Experiments** were conducted to verify the robustness of the algorithms. Worst-case scenarios for factors such as clockwise and counterclockwise tilt, degree of **focus** , magnitude of **brightness** and **contrast** , and shifted **images** were created and **evaluated** . Bench **testing** of three field-quality HDUs indicated that the **image analysis** algorithms are robust and able to **detect** the desired **image** features. Suggested future work includes development of a learning algorithm to automatically develop or revise...

Descriptors: Helmet mounted **displays** ; **Image** quality; Imaging systems; Optical **testing** ; Military applications; Data acquisition; **Image** sensors ; **Image analysis** ; Robustness (control systems); Algorithms
Identifiers: **Integrated helmet** and **display sighting systems** (**IHADSS**)

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Corporate Source: Messerschmitt-Boelkow-Blohm GmbH, Muenchen 80, Federal Republic of Germany
Conference Title: Large-Screen-Projection, Avionic, and Helmet-Mounted

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...Descriptors: Sensory Aids; HELICOPTERS; **DISPLAY** DEVICES...
Identifiers: HELMET MOUNTED **DISPLAYS** ; HEAD TRACKERS; HELICOPTER VISION SYSTEMS
?

HELMET MOUNTED SIGHT AND DISPLAY TESTING

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ABSTRACT

MBB has more than 10 years experience with HMS/D systems on helicopters. The results of conducted tests of Helmet Mounted Sights(HMS) and Helmet Mounted Displays(HMD) will be presented.

To compare the accuracy of the different HMS–Systems (on magnetic, acoustic or optical basis) we want to find and unify a test procedure for verification. The test conditions vary, dependent on the principle of the HMS system. Magnetic systems should be tested with the influence of magnetic disturbances, Ultrasonic systems under occurrence of noise and changing characteristics of the dispersion medium air, Optical systems under high luminance to check saturation effects of the sensors.

Modern Integrated Helmets (IH) consist of CRTs for displaying binocular images of TV– or Infrared–cameras and superimposed symbology and a second channel with Image Intensifier Tubes (IIT). Important points for checking CRTs are the resolution, distortion, homogeneity and brightness in day and night time. The most important test for the IIT–channel is the resolution measured as a function of luminance of the test pattern.

Tests of the basic helmet regarding head fit, earphone, centre of gravity, weight etc. are also necessary because these properties have an influence on the performance of the complete man–machine system.

1. INTRODUCTION

MBB is presently under contract to the German ministry of defence to study the update of the present **PAH 1** (anti–tank helicopter BO 105) and also to develop, in association with Aerospatiale/France, the TIGER second generation anti–tank helicopter (**PAH 2**). Both aircraft are expected to be capable of flying and fighting at day/night on similar missions.

The TIGER has installed in the helicopter nose a steerable platform with a 30° by 40° piloting thermal imager (TI). Currently the complete Pilot Visionic System (**PVS**) has two **monocular** Helmet–Mounted Sight/Displays (HMS/D) for the pilot and copilot cockpit. The monocular HMS/D is under contract by Sextant / VDO. The TI sensor alone can have a great disadvantage during a 24 hour mission. The absolute temperature characteristic or the emissivity of natural materials as a function of a 24 hour period will vary, ref. 1, 2, 3, 4 and 5 p. 93. A thermal zero contrast

(wash out effect) during rainfall or a so called **cross-over effect** are observed especially during twilight (morning and evening). Then the foreground is not detectable against the background.

Therefore the combination of the two visual aids: image intensifier tubes (IIT) and thermal imagers (TI), which are based on different physical principles, is better suited to fulfil the increased requirements of adverse weather conditions during day and night time. An **Integrated Helmet** (IH) with **binocular** vision (two CRTs and two IITs on the helmet) can display the images of the intensifier and the thermal images superimposed with flight symbology.

The available HMS–systems work on different physical principles. MBB has tested an electromagnetic AC–system in the FLAB program, ref.1 and during Gun Turret test trials. In 1990 an electromagnetic DC–system and an electro acoustic system were tested for the PAH 2 application, ref. 6.

Two suitable IHs with a helmet–mounted sight (HMS) were tested in the MBB visionic lab. In parallel, two PAH 1 helicopters have been equipped with the Racal **RAMS** incl. GEC Avionics **KNIGHT HELM** and with an Elbit **HALO** Night Vision and Mission Management Systems. These are to be used in troop trials at Celle, FRG, to gather experience of operations with state of the art equipment before deciding on the final configuration. The first time a Night Vision System with CRTs flight symbol presentation and IITs in an **IH KNIGHT HELM** including **see–through capability** were tested on a helicopter (HC). Presently, the PAH 1 system has no TI piloting sensor. Therefore a thermal image evaluation with CRTs was not possible, but a TV image was available in the HC for IH application.

2. HELMET MOUNTED SIGHT SYSTEMS

2.1 Experience of MBB with HMS/D–Systems

MBB has accumulated experience in several experimental programs in the last ten years. Significant programs are listed below.

- **HSF 4** Program (1980)
  In the HSF 4 Program (bad weather piloting) an electro–optical helmet tracker system (IHADSS) from Honeywell was used to steer a platform with optical sensors.
- **FLAB** – Program (1982)
  In the FLAB (Flying Laboratory) Program a piloting visionics system (PVS) consisting of FLIR and LLLTV on a stabilized platform, the symbology of a VDO symbol generator and a HMS/D–system of Ferranti were tested on a BO 105 helicopter. The HMS system was an electromagnetic AC system, ref.1.
- **Lucas Gun Turret** on BO 105 (1987/88)
  The Gun Turret was steered with an electromagnetic–AC HMS–system (Ferranti).
- **Tracker Tests GEC/TST** on a BK 117 for PAH 2 application (1990).
  In 1990 two helmet tracking systems were tested in a BK 117. The accuracies of an electromagnetic DC–system (GEC) and an electro acoustic system (TST) were measured and the sensitivity to some typical disturbances has

been tested. Also the influence of turning rotors has been tested in ground trials, ref. 6. The results will be discussed in this chapter.

- **PAH 1** flight trials in Celle with RAMS (with GEC Integrated Helmet) and HALO–systems (1990/91). Some results will be discussed in chapter 3.

2.2 Principles Of HMS – Systems

The purpose of the HMS is to steer either a platform with optical sensors, a landing light platform or a weapon platform in accordance with the head motion of e.g. a helicopter crew (Fig1). The measured values of the head motion angles must be of high accuracy and to be available with a minimum of time delay.

The helmet mounted sight systems can be realized using different physical principles. In the following the important HMSs of today are described.

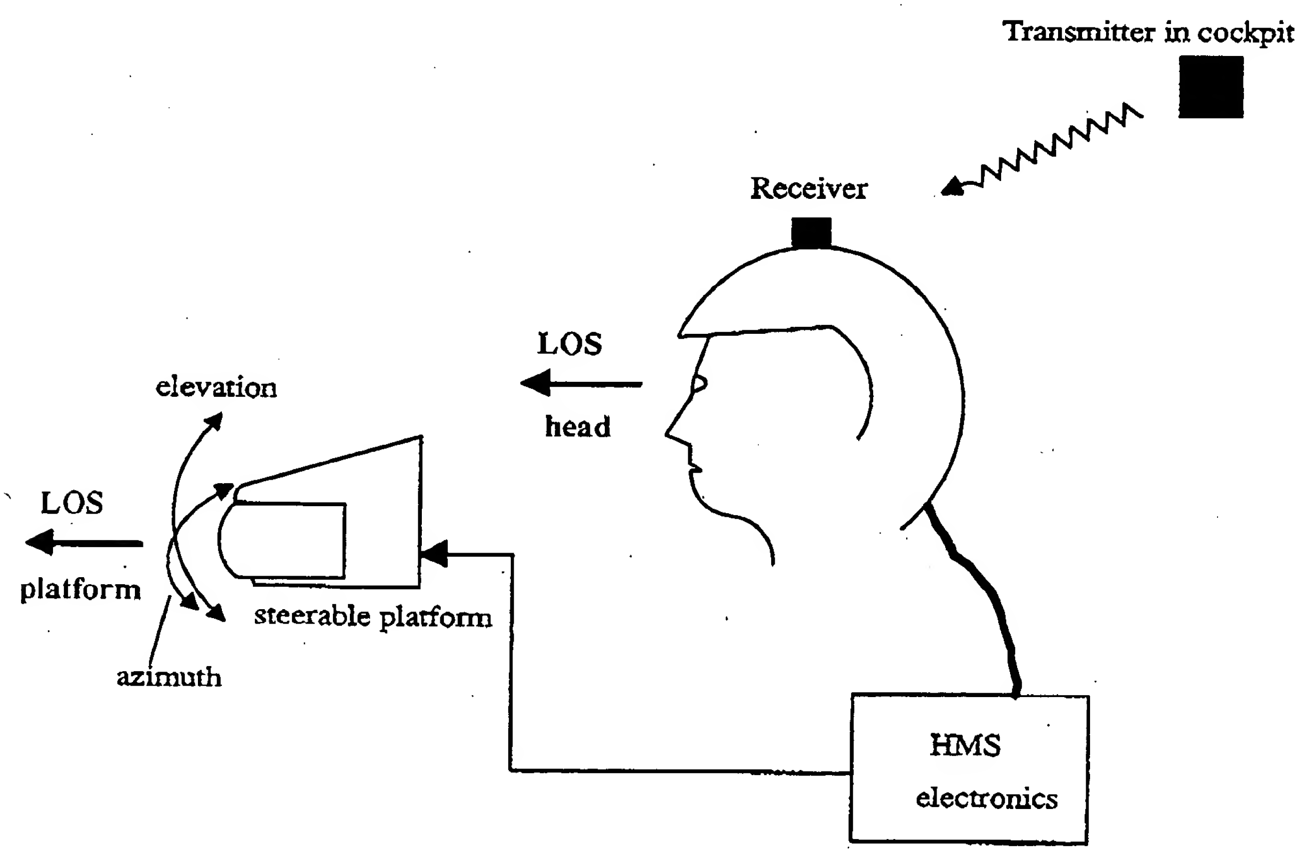

Fig. 1 Platform steering with e. g. an electromagnetic HMS–System (LOS...Line of Sight)

2.2.1 AC–Electromagnetic Systems (e.g. Polhemus, Ferranti, Sextant)

This system works on the basis of alternating electromagnetic waves. The transmitter which consists of 3 orthogonal coils, is mounted in the cockpit of a helicopter. The 3 coils transmit time–multiplexed electromagnetic AC–fields in 3 orthogonal orientations.

The receiver is mounted on the helmet and also has 3 orthogonal coils. With the induced voltages in the 3 receiver coils during radiation the position of the head inside the **head motion box (HMB)** and the head direction in azimuth, elevation and roll can be calculated.

AC–systems are very sensitive to metal parts inside the HMB. If the positions of the metals are fixed, the effects on the magnetic field can be compensated by cockpit mapping.

2.2.2 DC–Electromagnetic Systems (e.g. GEC Avionics)

DC–systems have also a transmitter located in the cockpit and a receiver mounted on the helmet, each of these with 3 orthogonal coils. The 3 coils of the transmitter are driven in time share with constant current and emit a constant electromagnetic field during the active time.

The receiver is working with the principle of a magnetometer and detects the constant magnetic field. Each of the 3 coils of the receiver detects the magnetic field, while transmitter coil 1, 2 or 3 is switched on. Additionally the magnetic earthfield is measured, and the measurements of the magnetic field emitted by the transmitters will be corrected by the earthfield.

DC–systems are not so sensitive to metals as AC–systems, but in presence of aluminium there exist eddy–currents due to induction, which limit the measurement frequency.

2.2.3 Electro Acoustic Systems (e.g. TST)

These systems consist of several (up to 6) ultrasonic transmitters and ultrasonic receivers. Either the transmitters are mounted on the helmet and the receivers in the cockpit or vice versa.

The transmitters emit a pulse of a constant ultrasonic signal time multiplexed. Each of the receivers detects the signal (if the receiver is inside the beam of the transmitter) and the electronics is able to calculate the distances to the transmitters according to the propagating time. Reference measurements of the sound velocity in air will be made in each measurement cycle.

With this redundant set of distances (not all distances are necessary) and the well–defined positions of the transmitters and the receivers , the helmet position inside the Head Motion Box can be calculated as well as the angles (in azimuth, elevation and roll) of the head in relation to the helicopter.

Disturbances could occur if the engines have ultrasonic noise near to the HMS – system frequency or if rapid changes in the characteristics (e.g. temperature, density) of the dispersion medium air occur.

2.2.4 Pattern Recognition systems (e.g. ELOP)

Optical pattern recognition systems work in principle with a CCD-camera (or other optical sensors) as a receiver in the cockpit. Either a geometric pattern which is painted on the helmet or a pattern of LEDs which is mounted on the helmet serves as a transmitter.

With the aid of image processing the video image of the pattern on the helmet will be evaluated, and the direction of the head will be calculated.

Possible disturbances could appear if saturation of the sensor occurs under e.g. direct sunlight illumination or if the geometric pattern shall be detected during night.

2.2.5 Electro Optical Systems (e.g. Honeywell, IHADSS)

The HMS-IHADSS, based on electro optical technology, uses for each cockpit two **Sensor Surveying Units** (SSU). The SSU are fixed installed and emit pulsed radiation in the IR-spectrum. On each side of the helmet are located two IR-detectors.

The function of this electro optical HMS is to calculate the direction of the operator's head (LOS) in relation to the aircraft reference coordinate system.

2.3 Test Procedures

2.3.1 Error Definition

An important point for understanding and comparison of tracker errors is an exact definition of the errors.

In Fig. 2 we have plotted the error definition. The diagram shows the statistics of measurements of a common value. Plotted on the y-axis is the occurrence of the feed back value of the measurements. There is a distribution of the values around a maximum of occurrence.

The maximum error is calculated by the difference between command value and feed back value plus the reproducibility of the feed back value. This maximum error has two different error types: the **systematic error** and the **statistic error.**

<u>Systematic error:</u>

The deviation between **command value** and measured **feed back** value depends on the command value. It can not be given as a general function, because the dependence is specific to the HMS-alignment. This is a systematic error. If the measurement system is well known and has a good reproducibility this error could be corrected. In case of a HMS-system this will be done by cockpit-mapping and after full system development the systematic error should be nearly zero.

Statistic error:

The most important error value is the reproducibility (σ). This value determines the minimal approachable system accuracy. The tolerance values can be defined in σ – or standard deviation (SD) values.

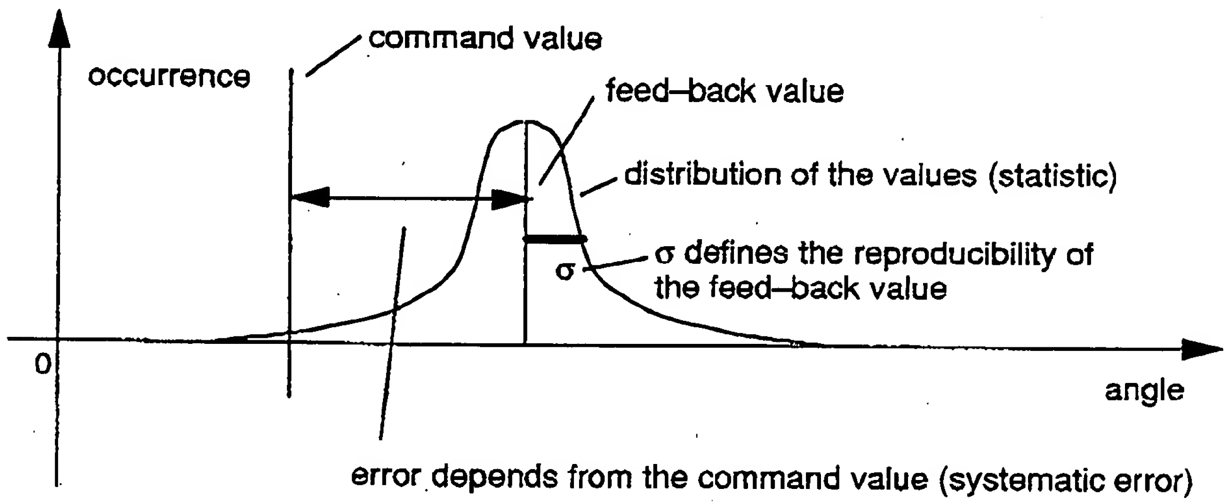

Fig. 2 Error Definition

2.3.2 Test Equipment

In fig. 3 the principle setup of the MBB accuracy test rig is shown. The basis of the rig are two metal plates. Three mounting screws allow a vertical adjustment and a tilting of the plates together. On the upper plate the stepper motor for the azimuth movement is fixed. The whole helmet fixture is mounted on this motor. Additionally an angular steel support is fixed to mount a second stepper motor with vertical axis. This motor is connected with a mechanical linkage which allows the movement of the helmet in elevation.

One requirement to the test rig is the use of non–metallic materials above the stepper motors to be able to test HMS–systems on electromagnetic basis. Metallic influences of the test rig itself cannot be accepted during testing.

The movement of the helmet in azimuth and elevation is fully automated and computer controlled. The command values can be given from a PC. A special software converts the angle values to motor steps and controls movement, velocity and acceleration of the motors. The maximal resolution of the stepper motors is 0.01° at a maximal velocity of 100°/s. The helmet movement in roll can be done manually in steps of 15°.

The maximal angle range of the helmet movement is limited by the mechanics of the test rig to:

- azimuth +/–180°
- elevation +25°, –30°
- roll +/– 45°.

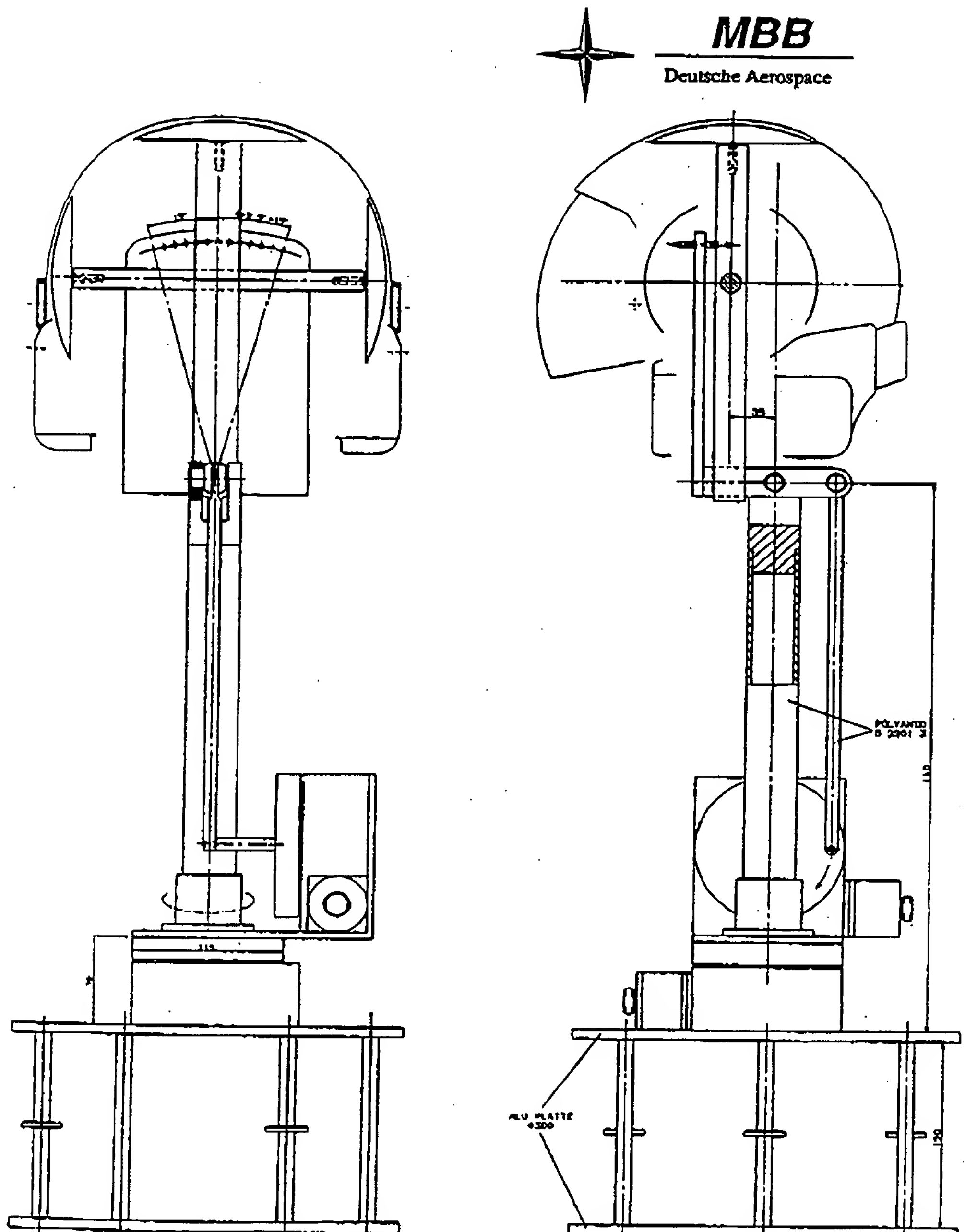

Fig. 3 MBB Test Rig for Helmet Mounted Tracker Evaluation

Adjustment of the test rig:

The movement of the helmet on the test rig in elevation is realized with two hinges. The mechanical construction was carried out with the requirement of a minimal slackness. The accuracy of the stepper motors and the accuracy of the total test rig has been checked experimentally. The experimental setup is shown in Fig. 4. A HeNe–laser is attached to the helmet which is fixed on the test rig. The helmet has been rotated in azimuth and elevation. Then trigonometrical functions of laserspot movement and geometrical boundary have to be calculated. Finally the angle–movement can be calibrated to the steps of the stepper motors using these results.

A further important point is testing the reproducibility of the rig to get information of the slackness about the mechanical arrangement. The helmet has been rotated several times forwards and backwards. Then the helmet has been commanded to drive to zero–position. The coincidence of this final position with the start position has been evaluated. As a result of these measurements we obtain the following values for the accuracy of the test rig.

The accuracy

- in azimuth 0.01°,
- in elevation 0.05°.

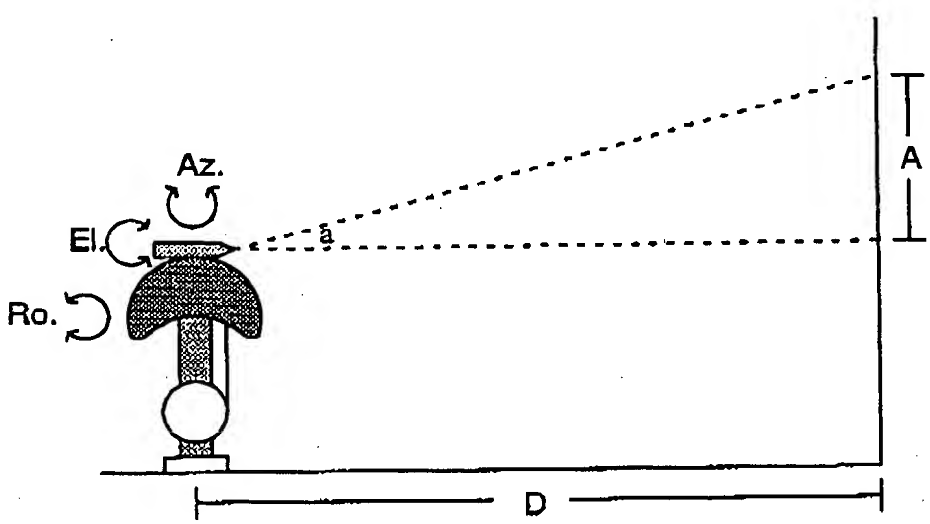

Fig. 4 Experimental setup for the test rig adjustments

Installation of the test rig in the helicopter (Fig.5):

- A wooden table which can be adjusted vertically is mounted over the pilot's seat.
- The helmet including the transmitter respectively receiver is mounted to the test rig.
- The test rig is fixed with screws on the wooden table. The test rig may be adjusted in height as well as in tilt to the helicopter frame.

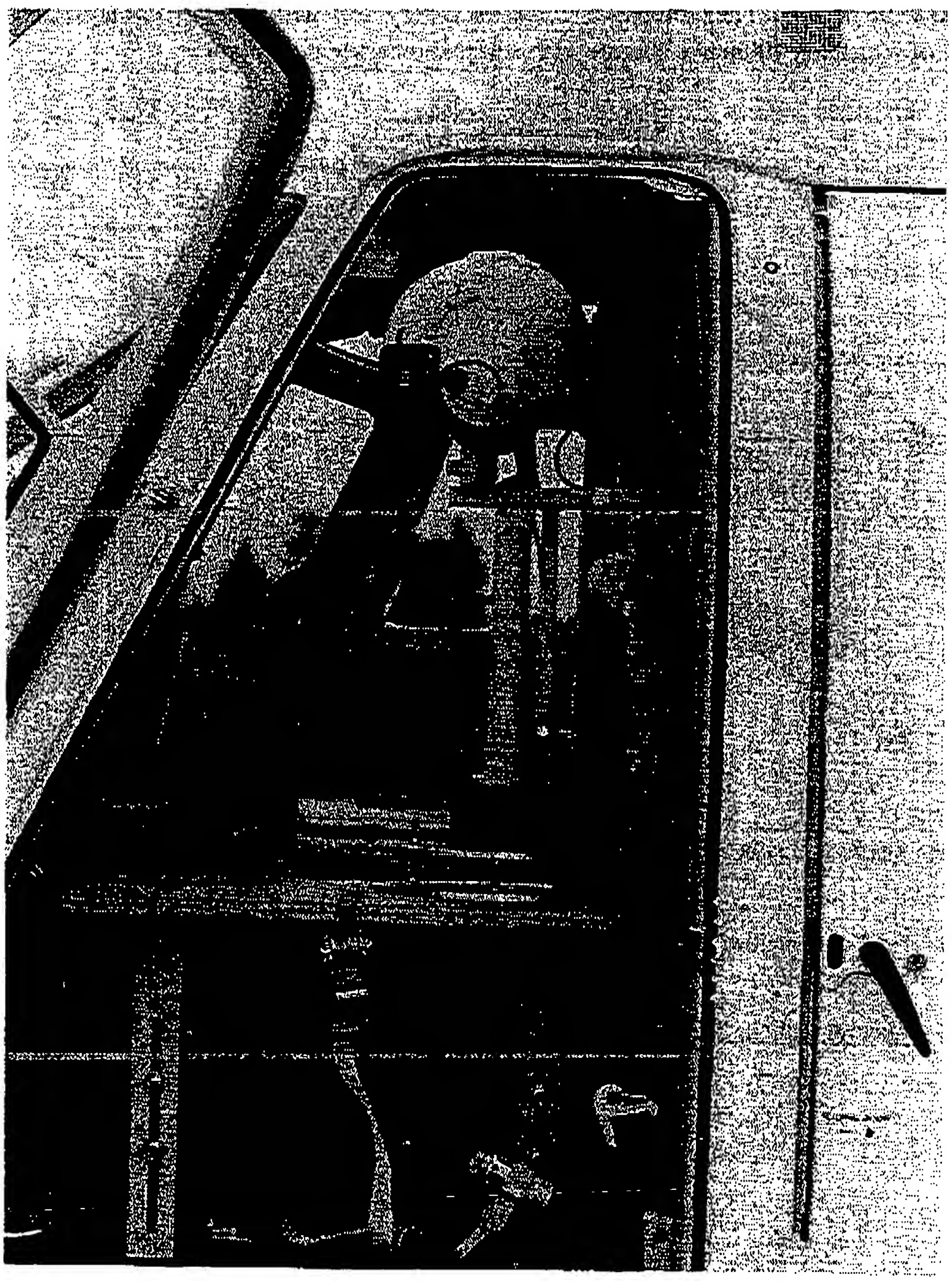

Fig. 5 Test Rig with Helmet and HMS in a BK 117 helicopter

2.3.3 Test Program

We have divided the test program into two parts, **static measurements** and **dynamic measurements**.

2.3.3.1 Static Measurements

The HMB is defined as the movement area of the pilots head. Inside this HMB the specified accuracy of the HMS–system has to be verified. The dimensions of the HMB vary from helicopter to helicopter, for an example Fig. 6 shows a HMB of 400mm x 400mm x 200mm with selected measurement points.

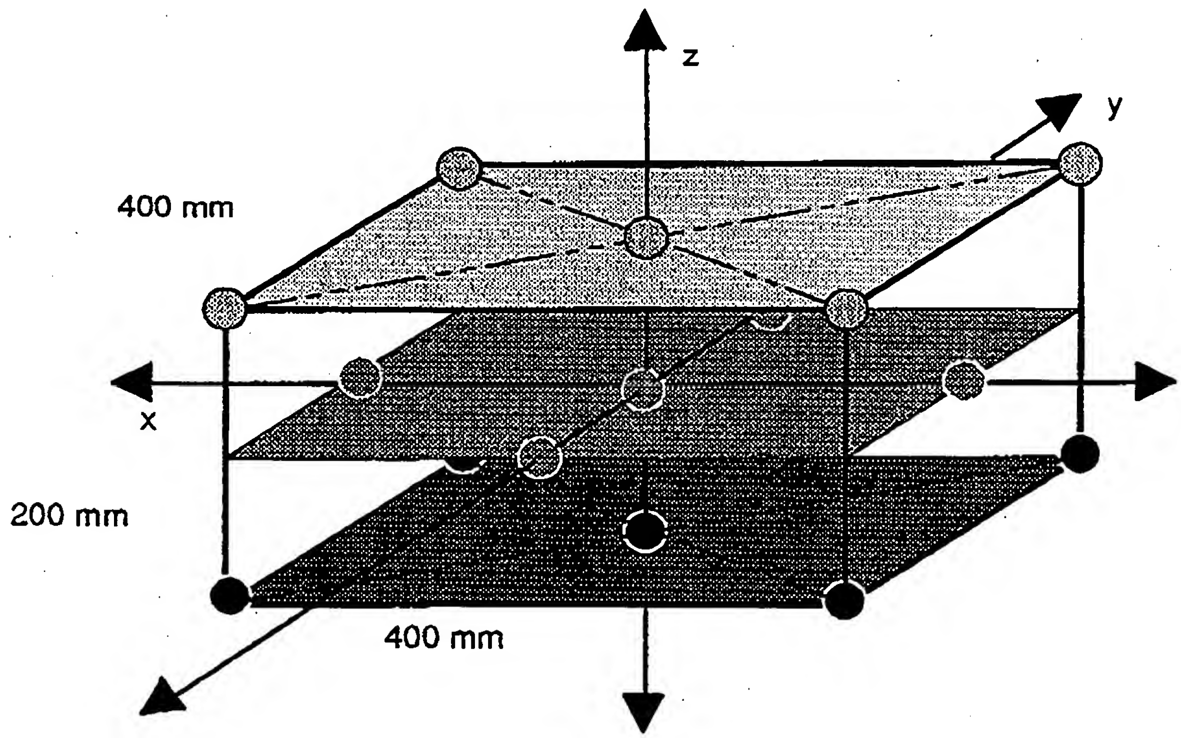

Fig. 6 Testing Positions inside the Head Motion Box

In the static part we propose the following measurements of the accuracy of the HMS–system:

<u>Complete set of measurements in the centre of the HMB:</u>

measurement point 1 (x=y=z=0)
roll angle: 0°

elevation angles:
0°, +20°, –20°
in combination with the azimuth angles:
0°, +/–5°, +/–10°, +/–15°, +/–20°, +/–25°, +/–30°, +/–45°, +/–60°, +/–75°, +/–90°

elevation angles:
+10°, –10°
in combination with the azimuth angles:
0°, +/–15°, +/–30°, +/–45°, +/–60°, +/–90°

Test procedure in the centre of HMB:

- A boresighting of the HMS–system is made first.
- For one fixed elevation angle the complete set of azimuth angles will be commanded step by step.
- For each point the HMS angle measurement values for azimuth, elevation and roll will be noted.
- This set of azimuth angles with the fixed elevation value will be measured for several (e.g. 10) times. Out of these values we calculate the maximum of the absolute error and the reproducibility (standard deviation).
- Measurement with the next elevation angle and so on.

Measurements of different roll angles are carried out in steps of 15° with azimuth = elevation = 0°.

Reduced set of measurements at different points inside the HMB:

A reduced set of measurement at the points 2 to 15 (compare Fig. 6) is:

Point–Nr.	X	Y	Z	Point–Nr.	X	Y	Z
1	0	0	0	9	–200	+200	+100
2	+200	0	0	10	–200	–200	+100
3	–200	0	0	11	0	0	–100
4	0	–200	0	12	+200	+200	–100
5	0	+200	0	13	+200	–200	–100
6	0	0	+100	14	–200	+200	–100
7	+200	+200	+100	15	–200	–200	–100
8	+200	–200	+100				

With all of the above mentioned points measurements of
elevation angles of 0°, +/– 20°
in combination with azimuth angles : 0°, +/– 15°, +/–30°, +/– 60°, +/– 90°
were made.

Remark: The test procedure is the same as above.

2.3.3.2 Dynamic Measurements

Test procedure:

- The test rig is mounted in the helicopter in such a way that the helmet is in the centre of the head motion box ($X = Y = Z = 0$).
- The test rig including the helmet carries out periodic movements in azimuth with constant elevation angle. For this movement the stepper motors may realize a maximum velocity of 100° per second. This is the maximum velocity of the motors. A leading edge and a falling edge with lower velocity is necessary.
- In the computer protocol the output values can be compared with the stimuli and may be checked for achievement of the maximum values and the maximum velocity at the zero point.
  The command and feed–back value are connected for this purpose to an x–t recorder (fig. 7).

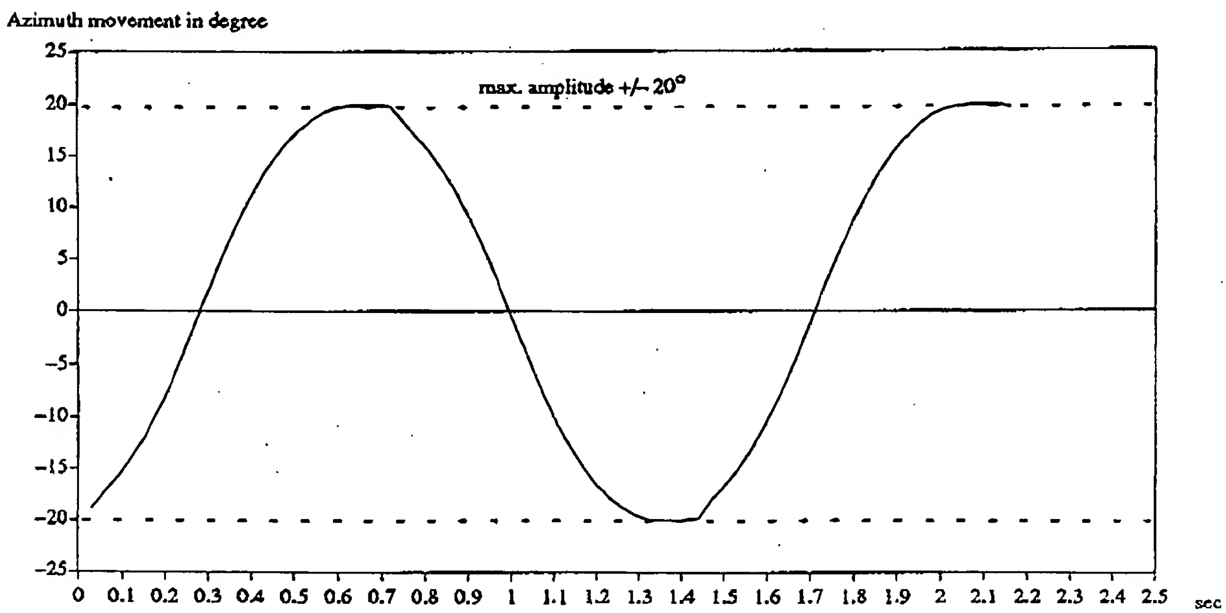

Fig. 7 Time Plot of the dynamic measurements (DC–EM system), max. test rig velocity is 100°/s.

2.3.3.3 Additional Measurements

The following additional measurements have been included in our measurements:

- o controlling the longtime stability of the electronics (2h)
- o qualitative disturbance measurements, especially for the tested HMS, e.g.:
  - AC–,DC–systems: additional metal parts between transmitter and receiver
  - DC–systems: influence of the magnetic earthfield
  - Acoustic systems: switching on the helicopter ventilation, thermal changes in the cockpit, as e.g. direct sunlight
  - Optical systems: sensor saturation due to e.g. direct sun illumination
- o influence of running engines and rotors:
  - electric disturbances
  - acoustic disturbances
  - helicopter vibrations

2.3.4 Test Evaluation

Static measurements:

- o Calculation of mean values, standard deviation (n–1) and the absolute errors (command– minus feed–back values) according to the above mentioned measurement protocols. As result we get the absolute errors as well as the reproducibility.
- o The following diagrams were selected:
  - absolute error of **azimuth** and standard deviation as a function of the azimuth angle (Fig. 8)
  - absolute error of **elevation** and standard deviation as a function of the azimuth angle
  - absolute error of **roll** and standard deviation as a function of the azimuth angle

The result of a complete measurement are about 100 diagrams. For an overview of the accuracy a data reduction has to be implemented!

- o Data reduction made for each measurement point:
  - Calculation of the mean value of the absolute errors and the mean value of the standard deviations for all **azimuth angle values**, which were measured during one scan of azimuth with constant elevation angle (Fig. 9). The maximum and the minimum should also be mentioned to see the bandwidth of the error.
  - Calculation of the mean value of the absolute errors and the mean value of the standard deviations for all **elevation angle values**, which were measured during one scan of azimuth with constant elevation angle. The maximum and the minimum should also be mentioned to see the bandwidth of the error.

- Calculation of the mean value of the absolute errors and the mean value of the standard deviations for all **roll angle values**, which were measured during one scan of azimuth with constant elevation angle. The maximum and the minimum should also be mentioned to see the bandwidth of the error.

o With these data new diagrams may be drawn with

- mean value and standard deviation of all measured azimuth angle values (with constant elevation angle) as a function of the **elevation angle** for one point inside the head motion box (Fig. 10).
- mean value and standard deviation of all measured azimuth angle values (with constant elevation angle = 0°) as a function of **one dimension of the head motion box** (Fig. 11).

o In a further step the average of the mean values of each elevation angle (in our case 5) can be taken again. The result is one mean value for one angle. It is advantageous to mention also the maximum and minimum value to see the bandwidth of the error.

This error has nothing to do with an individual error at one point, but this value is suitable for the comparison of different systems, which have been tested in the same manner.

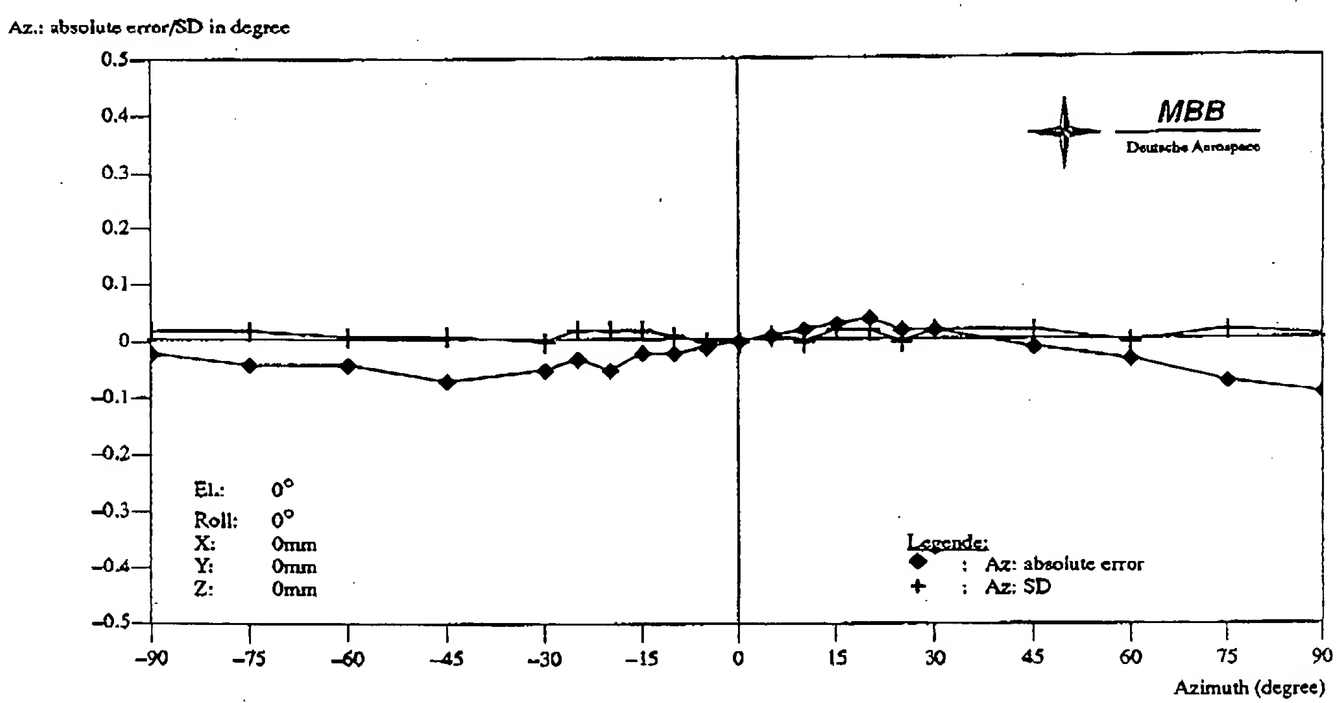

Fig. 8 Absolute error of azimuth and standard deviation as a function of the azimuth angle (DC-EM system).

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El. angle		AZIMUTH (°) min.	AZIMUTH (°) mean	AZIMUTH (°) max.	ELEVATION (°) min.	ELEVATION (°) mean	ELEVATION (°) max.	ROLL (°) min.	ROLL (°) mean	ROLL (°) max.
0°	abs. error	0.00	**0.03**	0.09	0.01	**0.10**	0.26	0.00	**0.14**	0.52
	SD	0.00	**0.01**	0.02	0.01	**0.03**	0.04	0.01	**0.03**	0.06
+10°	abs. error	0.11	**0.17**	0.21	0.12	**0.46**	0.61	0.04	**0.38**	0.65
	SD	0.00	**0.02**	0.02	0.02	**0.03**	0.05	0.02	**0.04**	0.08
−10°	abs. error	0.00	**0.07**	0.15	0.07	**0.15**	0.21	0.32	**0.48**	0.53
	SD	0.00	**0.01**	0.02	0.00	**0.02**	0.04	0.00	**0.02**	0.04
+20°	abs. error	0.02	**0.19**	0.37	0.41	**0.58**	0.68	0.54	**0.75**	1.08
	SD	0.00	**0.04**	0.07	0.00	**0.04**	0.11	0.02	**0.05**	0.10
−20°	abs. error	0.00	**0.17**	0.57	0.00	**0.10**	0.16	0.76	**0.90**	1.21
	SD	0.00	**0.04**	0.12	0.02	**0.10**	0.26	0.03	**0.15**	0.30

Fig. 9 Mean value of the absolute errors and the mean value of the standard deviations for all azimuth angle values, which were measured during one scan of azimuth with constant elevation angle (DC–EM system).

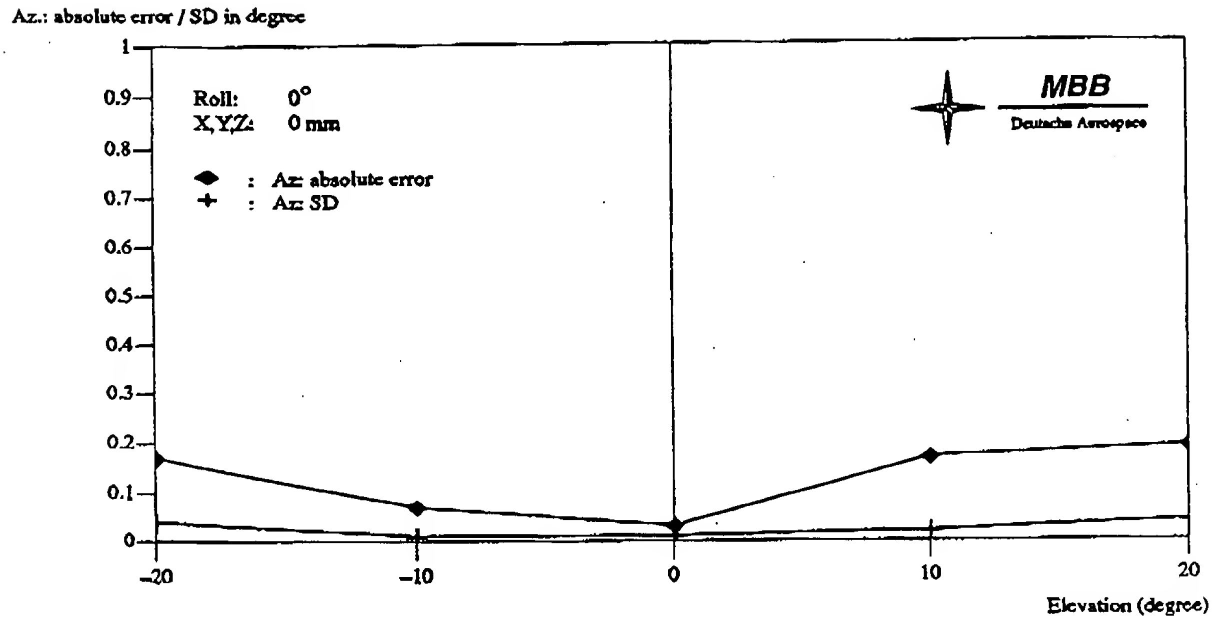

Fig. 10 Mean value and standard deviation of all measured azimuth angle values (with constant elevation angle) as a function of the elevation angle for one point inside the head motion box (DC–EM system).

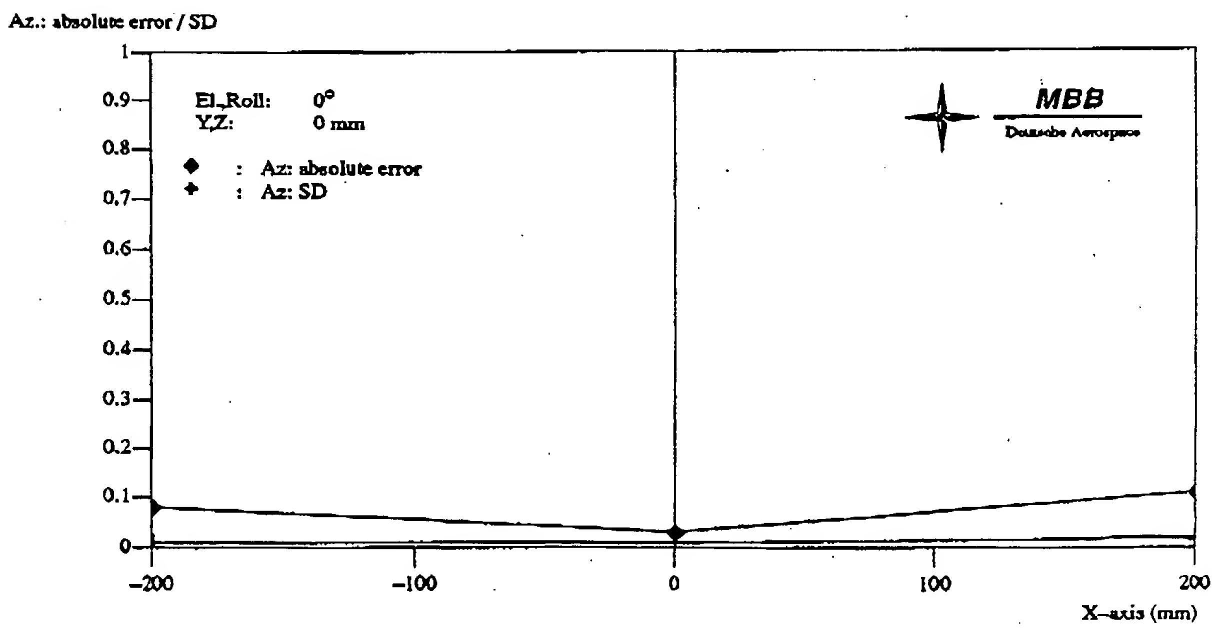

Fig. 11 Mean value and standard deviation of all measured azimuth angle values (with constant elevation angle = 0°) as a function of one dimension of the head motion box (DC–EM system).

3. INTEGRATED HELMET SYSTEMS "WITH SECOND SENSOR"

3.1 Review of existing Integrated Helmets with CRTs and IITs

3.1.1 GEC Avionics KNIGHT–HELM

The basic KNIGHT HELM provides NVG operation by IITs and the CRTs generated displays of TI and symbology (FOV 35° circular). This combined IIT/CRT Helmet Display offers a high level of system flexibility and failure survival. The equipment is suited to in–service life, because all the electro–optical parts are protected by the helmet shell. New materials are being used for this helmet shell to retain strength and impact protection in a lighter weight structure. The optical modules are very compact and can be adjusted for inter pupillary distance (**IPD**) and can be moved slightly (up/down and fore/aft) with respect to the helmet shell. The see–through capability is mandatory. PAH 1 trail uses **one day/night module** but GEC has now developed a modular concept for IH. Fig. 12 shows the GEC KNIGHT HELM, ref. 7.

Fig. 12 **Integrated Helmet KNIGHT HELM** from GEC Avionics with IITs and CRTs Displays using flat eyepieces like mini–HUD prisms.

3.1.2 Honeywell MONARC (Monolithic Afocal Relay Combiner)

The basic helmet has a shell which can be fitted with an individual form fit liner. With this good adaptation the helmet provides a comfortable centre of gravity. On both sides of the basic helmet are adapted the optical modules with biocular (only one image source) CRT displays and binocular IITs (FOV 35° circular). The images of these two channels are displayed with a monolithic afocal combiner to the eyes. The see–through vision of the wearer is ensured and the field of regard is slightly obstructed. Each of the turnable combiners is part of the optical module. The optical modules can be adjusted for IPD and may be moved up and down. The MONARC was tested for several days at MBB lab and was flown for several days on PAH 1. Fig. 13 shows the Honeywell MONARC, ref. 4, 5 and 9.

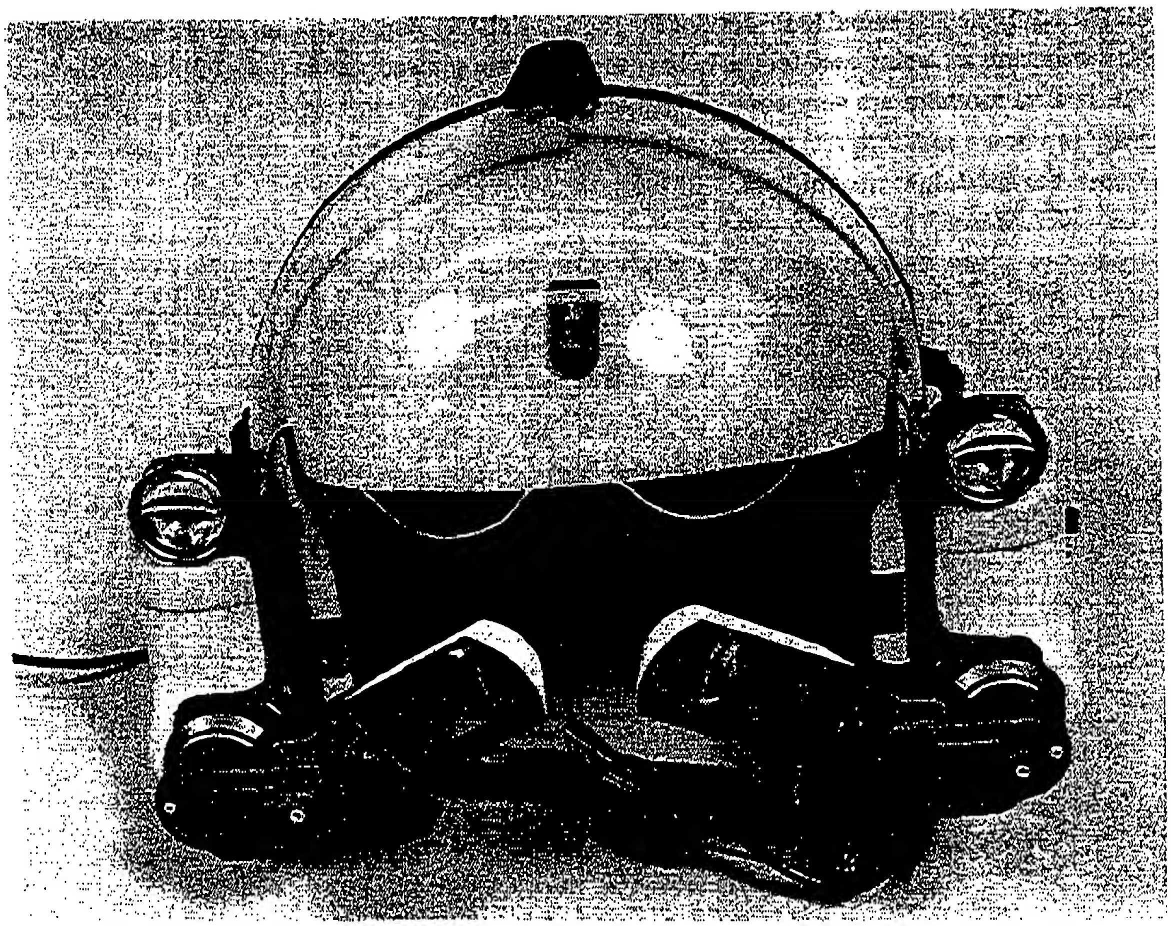

Fig. 13 **Integrated Helmet MONARC from Honeywell with CRTs and IITs Displays using turnable combiners.**

3.1.3 Kaiser Electronics STRIKE EYE

The basic helmet has a shell which can be fitted with an individual form fit liner. On both sides of the basic helmet the optical modules with biocular (only one image source) CRT displays (30° by 40° overlap) and binocular IITs (FOV 30° circular) are adapted in eye position. The images of these two channels are displayed with combiners from above the eyes. The see–through vision of the wearer is ensured. The combiners are retractable and adjustable, ref. 4 and 10.

3.1.4 Sextant/VDO Helmet Mounted Sight/Display with Light Intensifiers

The basic helmet is personalized and is generally kept by its wearer. It is a new design, using modern composite materials and optimization techniques. This was necessary to provide adequate mechanical mounting for the Day/Night Module, minimizing the helmet weight. On both sides of the basic helmet the optical modules with biocular (only one image source) CRT displays and binocular IITs (FOV 40° circular design) are adapted in eye position. The images of these two channels are displayed with combiners from above the eyes. The see–through vision of the wearer is ensured. The combiners are retractable and adjustable. Since June 1989 a technical exchange took place between Sextant/VDO and Kaiser Electronics mainly in ergonomy field. The current status of the IH is readiness for TIGER development, if go ahead will be decided, ref. 11.

3.2 Lab–Tests and HC–Trials with PAH 1 Demonstrator

The testing at the MBB laboratory was implemented for two state of the art Integrated Helmets, KNIGHT HELM and MONARC. Fig. 14 shows the test method for the optical IIT resolution measurement. The distance of the test target to the eye position is approx. 7m. The test pattern is a USAF 1951 target with approx. 70% contrast.

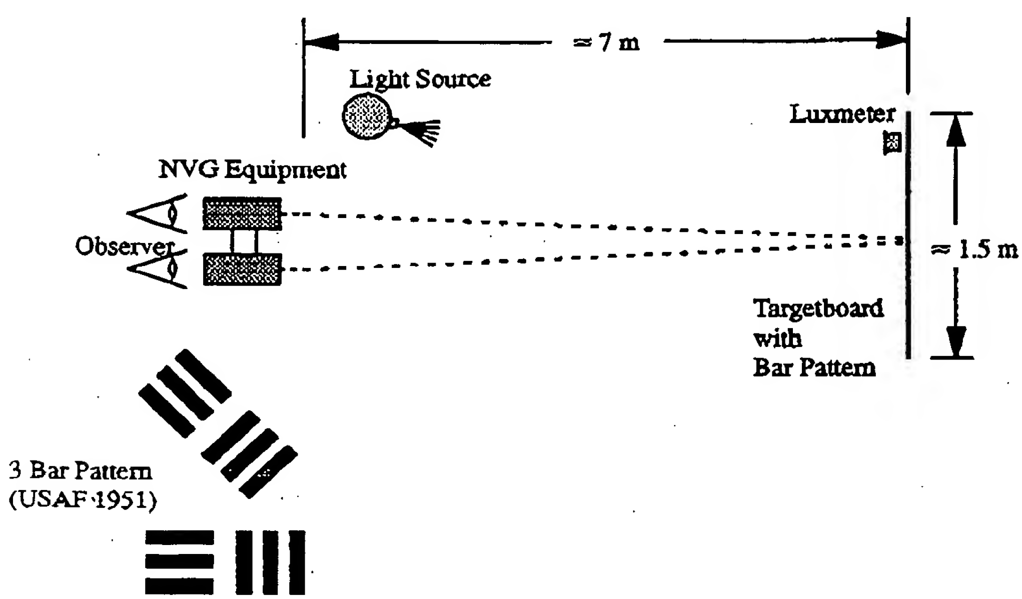

Fig. 14 Top View of the Test Set to measure the Resolution and Sensitivity of NVG's and Integrated Night Vision Helmets as a function of illumination level.

During extensive flight trials (May 90 to Jan. 91) the German Army compared the established Philips Night Vision Goggles (NVG) 3rd generation tubes with the KNIGHT HELM. In the landscape of Northern Germany, the lighting conditions under which the goggles must perform can vary over almost four decades, from 0.1 mLux to almost 500 mLux, presenting any NVG with a very severe task. The German Army is expected to fly in a particularly stringent combination of circumstances: overcast starlight, mist and precipitation at very low altitude, two or three meters above ground level between areas with obstacles. The ambient light available may be only 0.3 mLux or below. The experience shows that there is no substitute for flight trials, e.g. lab and simulator tests only, to completely understand an IH.

The **Philips NVG** is the benchmark of the IHs:
The Philips NVG comprises two identical straight through monoculars with fixed objective focus (approx. 10m to infinity) and adjustable eyepiece focus. The objective is a 26 mm focal length, F–No.1.2 lens with a circular field of 42° and a magnification of 1:1. The two monoculars are held together at the front on a tilting hinge for adjustment of IPD at the rear. Adjustment of IPD will vary the FOV overlap. A torch lamp is attached to the front of the binocular channels and operates by a lip switch to illuminate the cockpit, ref. 12. The resolution measurement will be shown in chapter 3.4.

The main results of IH including problem areas will be discussed in the next chapters.

3.3 Basic Helmet including optical modules

Form Fit Liners should ensure that the helmet is **personalized** to each pilot and provide a comfortable platform for the **Integrated Helmet** with correct performance, lifetime, compliance and comfort. One of the particular problems GEC Avionics has encountered through the trials is that one helmet liner is not ideally suited to be used in two helmets of different weights, i.e. night vision only helmet and helmet with night vision and CRTs (compare chapter 3.6.). When GEC Avionics supplied the second helmet for evaluation (which contained only night vision without CRTs), there was some criticism by the pilots that the helmet **shell** was smaller and less comfortable than the first helmet supplied. In fact, the two helmets were exactly the same size despite contrary pilots comments. Indeed the second helmet was constructed with slightly more carbon fibre. This produces a much stronger shell which provides greater protection in the event of crash landing, although the shell may create the impression that it has a smaller size.

The **Centre of Gravity** (CG) of the two helmets is different. If the CG of the IH is correct, the subjective impression of the two helmets being too small may diminish. Fig. 15 shows the definition of CG for helmets.

Chin Cup: Originally the KNIGHT HELM was supplied with a leather padded neck strip. The pilots expressed concern that the neck strap was uncomfortable and did not aid helmet stability. The neckstrap was exchanged for a chin strap.

During the PAH 1 flight trials it became obvious that regardless of the parameters, the **exit pupil** is perhaps the most important consideration along with **weight, field of view** (FOV), **resolution** and **brightness gain**. A large exit pupil (greater than 13 mm) provides a very user friendly system, giving great confidence and comfort by knowing that there is a large night vision window to look through. If the IH shall be moved, the pilot will not suddenly loose his vision of the outside and IIT image. A drawback of a large exit pupil is the increase of optical module weight.

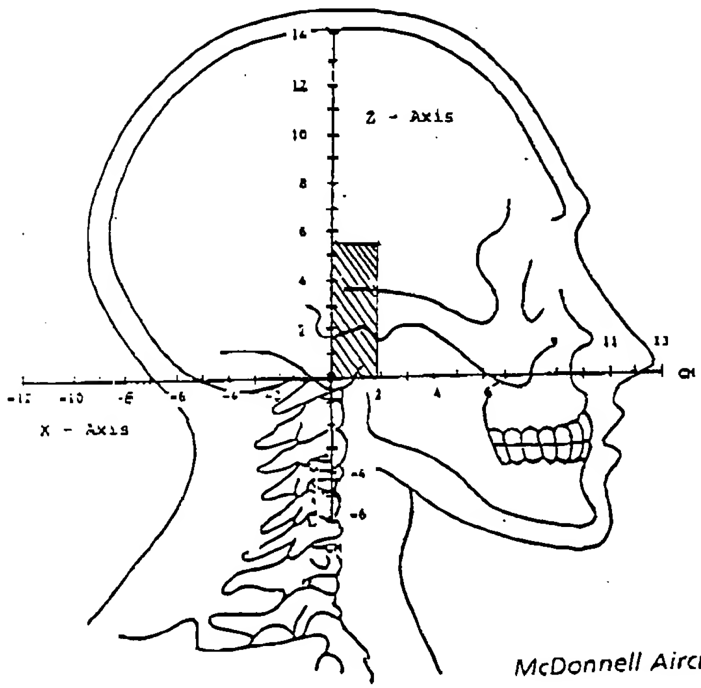

Fig. 15 Centre of gravity definition for human head; coordinates axis shows neck support. The Head CG is higher and forward. Helmet CG should be inside the dashed area.

Other important parameters of a good IH layout are:

- o adjustment comfort for: inter pupillary distance, vertical, fore/aft/tilt (eye relief)
  remark: personal adjustment on helmet;

  divergence setting (stereo acuity), dipvergence tolerance, overlap, magnification 1:1
  remark: adjustment at supplier.
- o good look around total field of regard (peripheral vision) with low obscuration of optical combiner edges, CRT– and IIT–FOV with 40° circular, magnification 1:1.
- o crash protection
- o Man Machine Interface (MMI): –wearing comfort, –usage of helmet, –cockpit workload, –Laser protection, –NBC–mask compatibility, –HUD–compatibility, –cockpit illumination compatibility with IIT channel
- o reliability and flight safety requirements: catastrophic fault should be zero
- o speech / communication
- o noise damping / active sound attenuation

- o easy modes / functions
- o fulfillment of environment requirements specially temperature, vibrations, EMC / NEMP
- o depth, motion (optical flow) and stereoscopic view perception:biocular display gives a square root 2 advantages for two eyes in MCT (modulaton contrast thresholds), binocular IITs in an IH have a base line of approx. 260 mm compared to approx. 60 mm IPD in NVG, remark: problems of distance estimation arises and new training is necessary compared to NVG HC flight, magnification problems! Ivan Sutherland has said, ref. 4, p. 82 and ref. 13: "Although stereo presentation is important to the three-dimensional illusion, it is less important than the change that takes place in the image when the observer moves his head. Psychologists have long known that moving perspective images appear strikingly three-dimensional even without stereo presentation", ref. 5 and 9.
- o quick release connector with high tension safety, umbilical cable
- o Boresighting Reticle Unit (BRU) in the cockpit with easy alignment functions

3.4 Image Intensifier Tube – Testing

Tests were carried out at MBB on the optical performance of the IITs: Philips 3rd gen. NVG, KNIGHT HELM and MONARC. The left hand and right hand IITs were tested together with a two alternative forced choice (2AFC) method to determine resolution. Additionally the USAF 1951 test pattern was used. The objective lenses were focussed correctly with the 7m object distance. A fixed color temperature light source from an integrated sphere was available. The illumination levels were measured at the IH and in the target plane. The results are shown in fig. 16.

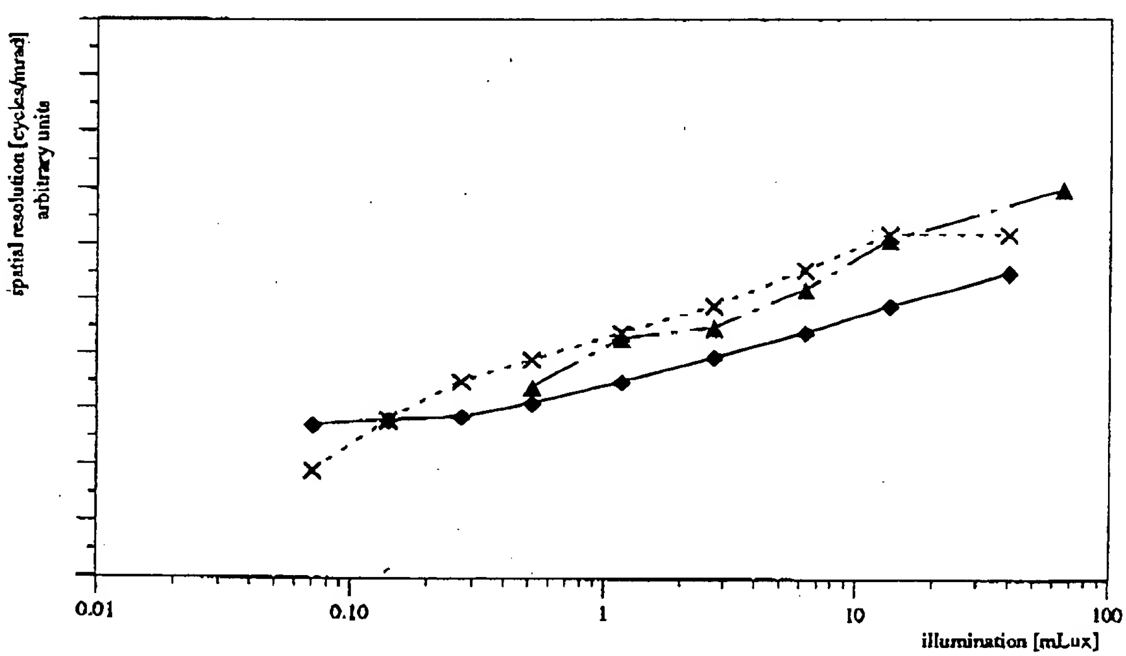

Fig. 16 Resolution tests for 3.Gen. NVG FOV 42° circ.(————), KNIGHT HELM FOV 35° circ. (– · – · –) and MONARC FOV 35° circ. (········)

Other important parameters of a good IIT layout are:

- good brightness at low background illumination (LBI) is necessary
- Automatic Gain Control (AGC) lies between 1500 and 2900 at 10^{-2} cd/sqm
- daylight filters (neutral filters) for training purpose are desirable with attenuation of 10^{-7} and 10^{-9}
- 645 nm cut off filters with antifluorescent coating were used
- image quality: snow/scintillations (S/N) and homogeneity over combiner must be good
- tube life time, (InSb sealing!), temperature range with full performance between –12° C and 42° C

3.5 CRT–Testing

A 1" tube has a 25mm diameter faceplate with a screen diameter of 19mm. The spot (pixel) size is approx. 18um at 200ftL or 25um at 500ftL for P43 Phosphore (gaussian profile). If one considers a future requirement for a high luminance (approx. 10 000ftL) allowing daylight raster viewability then this will require at the present time a further sacrifice in resolution with a low drive value of 24um and a high drive value of 32um.

Other parameters of a CRT are:

- high brightness necessary for day flight with symbology, same brightness of the two images
- 10 grey levels with relative good brightness and contrast
- high resolution image, approx. 18um spot size or approx. 40 Lp/mm with good quality/homogeneity/ min.distortion, same for both CRTs
- high brightness (approx. 4 000 ftL) with poor resolution and reduced grey levels.
- no vignetting of image edges, low distorsion
- ghost image (double image) should be zero; coating problems at IIT/CRT–beamsplitter (reflections)
- fast Stroke (cursive) symbols written in Raster flyback / Raster display of sensor video possibility
- head roll compensation necessary
- optimized overlap, divergence and dipvergence of the two channels
- raster scan generator shows 0.8 cycle/mrad for KNIGHT HELM and MONARC
- circular test pattern shows low distortion,
- electronic distortion compensation necessary
- high voltage isolation

3.6 Mission aspects and optical day / night modules

A Tactical Flight (TF) including Nap of the Earth (NOE) mission will occur approx. 25% of total flight hours and a Night Tactical Flight (NTF) approx. 15% with visual aids, that means with IIT during night or TI during day/night. An IH improves the safety analysis drastically. If a night flying system with two night sensors uses the IITs, then the HMS, the CRTs and TI sensor platform can have a failure. The IITs have two battery packs which are independent from the HC power supply. The **reliability** and **flight safety** analyses including a **catastrophic fault/event** improves tremendously.

Symbology projection into one eye or two eyes for day/night application: The IH KNIGHT HELM incorporates a binocular arrangement with two separate IITs and separate **left** and **right** CRT; thus enabling full flight symbology or outside world scene via a thermal imager to be displayed in the helmet. The technique of presenting information to a pilot in this manner is complex and requires the pilot's eyes and brain to integrate the information displayed, to produce one image and not a double image.

The CRTs of KNIGHT HELM are nominally focussed to be compatible with the IITs, and the optics are designed to cope with a certain latitude in the point of focus of the pilots eyes, i.e. whether he is looking close or distant. When using TI, the IITs should be switched off, and the pilots view one image from two CRT sources. This is a usual technique. When using IITs plus flight symbology the pilot has to integrate one image from four sources; two IITs plus two CRTs. This is complicated by the **focussing** and **convergence** properties of the eye. In any case the magnification of the systems should be 1:1. Certain pilots flying the PAH 1 have had difficulties in focussing upon the flight symbology in the helmet. GEC has made investigation to confirm that the **focal plane** of the two CRTs matches that of the IITs.

Whilst two CRTs are mandatory for night flying with thermal images, two CRTs may not be necessary for night vision with flight symbology. In fact studies have shown that a pilot receiving information from CRT to one eye may not be able to distinguish which eye is receiving the information. Double images of the flight symbology or the scene appear as eye convergence is shifted to fix nearby objects while the collimated symbology is at infinity focus, by definition.

To improve the situation with PAH 1 GEC Avionics implemented a switch to allow the pilots to select manually left CRT, right CRT or both. The results were favourable; the problems associated with image separation and headaches when using flight symbology decreased and the pilots were at liberty to use two CRTs again for TI.

Auto Contrast/Brightness Sensor for CRTs: Pilots have expressed dissatisfaction that the brightness and contrast levels of the flight symbology in the **helmet–CRTs** are only manually adjustable. Under certain ambient light conditions at night, the outside light level is bright, requiring the symbol brightness in the helmet to be increased. But when the pilot then looks into foreground for example, the symbols are **too** bright compared with the night vision scene. To improve this situation GEC Avionics are implementing an auto–contrast control. When auto–contrast is selected, a photo detector assembly mounted on the helmet will increase or decrease the pre set contrast/brightness level dependent upon whether the pilot looks into a bright or dark area. This sensor will only affect the symbology displayed by the CRT since the IIT incorporates a separate auto brightness function. Fig. 17 shows the problem area of day/night transmission splitting.

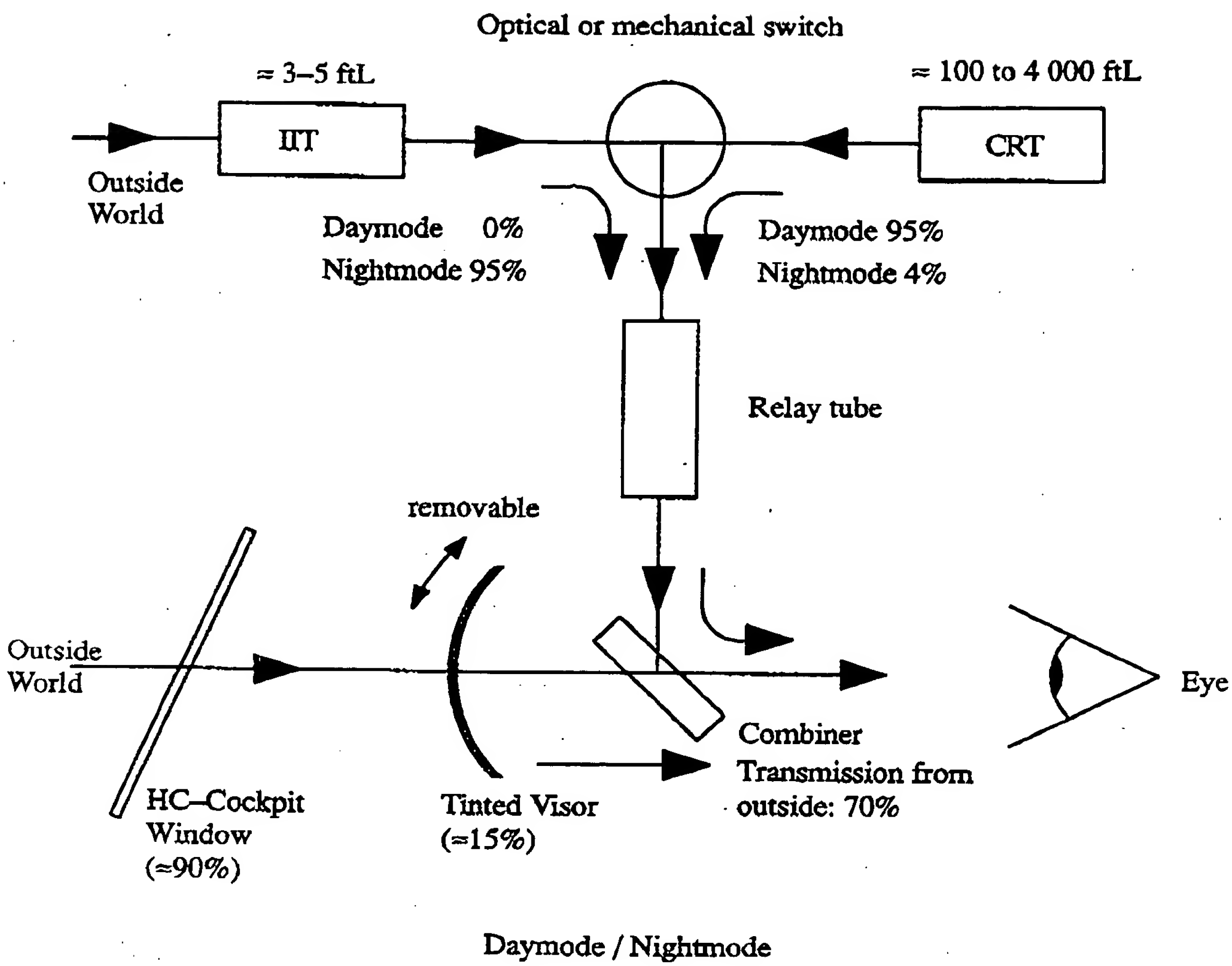

Fig. 17 Display brightness performance to the human eye

- **Day Module and Night Module each separate:**
  advantages:
  - modules separate from basic helmet, each pilot has his own basic helmet (personalized), opt. modules belong to HC
  - min. weight on helmet for each day/night mission
  - good transm./brightness/contrast on daytime with 2 CRT only
  - good transm./bright./contrast in the night with 2 CRT and 2 IIT

  drawbacks:
  - change of modules necessary during twilight
  - storage problems in HC

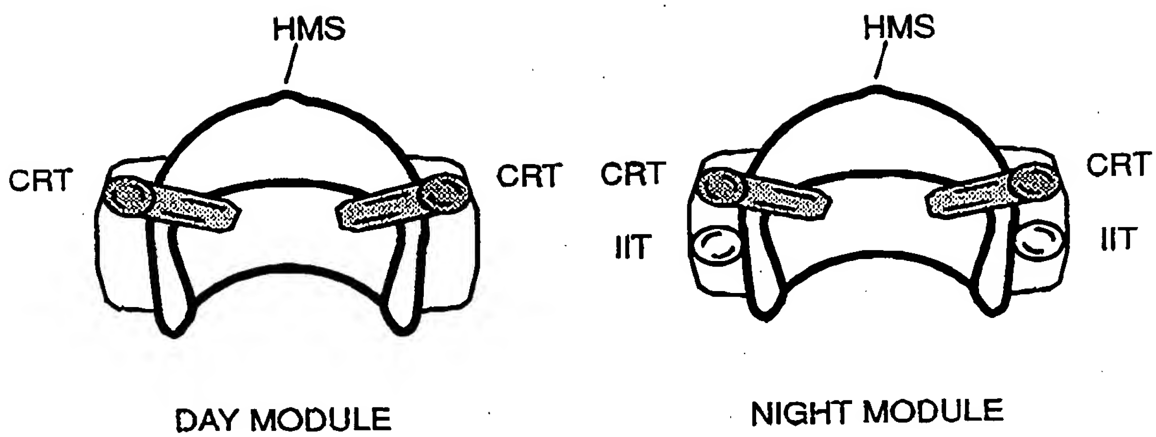

Fig. 18 Weight optimized **day and night module**

o **One Day/Night Module:**

This configuration works very well in a night mission if the combiner has e.g. 70% transmission for IIT/CRT channel and a high IIT gain of approx. 5cd/sqm luminance level. However the drawback in daytime is that the combiner has an outside transmission of only 30%. This is to low for a cloudy/overcast day. To improve the day transmission for the CRT channel (brightness up to 34 000cd/sqm) an optical or mechanical switch can solve the problem, compare Fig. 17 .

advantages:

- no storage problems in cockpit
- mission can be flown safely without change of modules

drawbacks:

- weight of helmet higher than with separate modules
- transmission levels not optimized

Resume from GEC, ref. 5, p.92:

- It is possible to optimize a helmet display for DAY use.
- It is possible to optimize a helmet display for NIGHT use.
- But it is not possible to optimize **one helmet** display for both day and night use.

3.7 Future Integrated Helmet Developments

o **IIT with CCD** integrated, ref. 5 p. 88 and p.100 and ref. 14.

This configuration may have a high outside world transmission of approx. 70 to 85%, while the CRT brightness to the eye is high enough for night application. The IIT image is converted with a CCD to video standard and displayed with a CRT to the eye. The alignment of IIT and TI channel is much easier. No ghost images caused by reflections occur. Electronic image processing for image fusion can be used as growth potential.

A strong drawback is the dependence of power for both channels. If HC power fails no redundancy will exist. The flight safety/reliability decreases with this arrangement. The TI/IIT–CCD sensors are located in the HC nose below the pilots design eye point steered by HMS. This can produce problems of parallax, wrong depth perception and apparent motion. However if the IIT channels are helmet mounted, there exist problems with switching of two different visual reference points, compare fig. 19 and 20 .

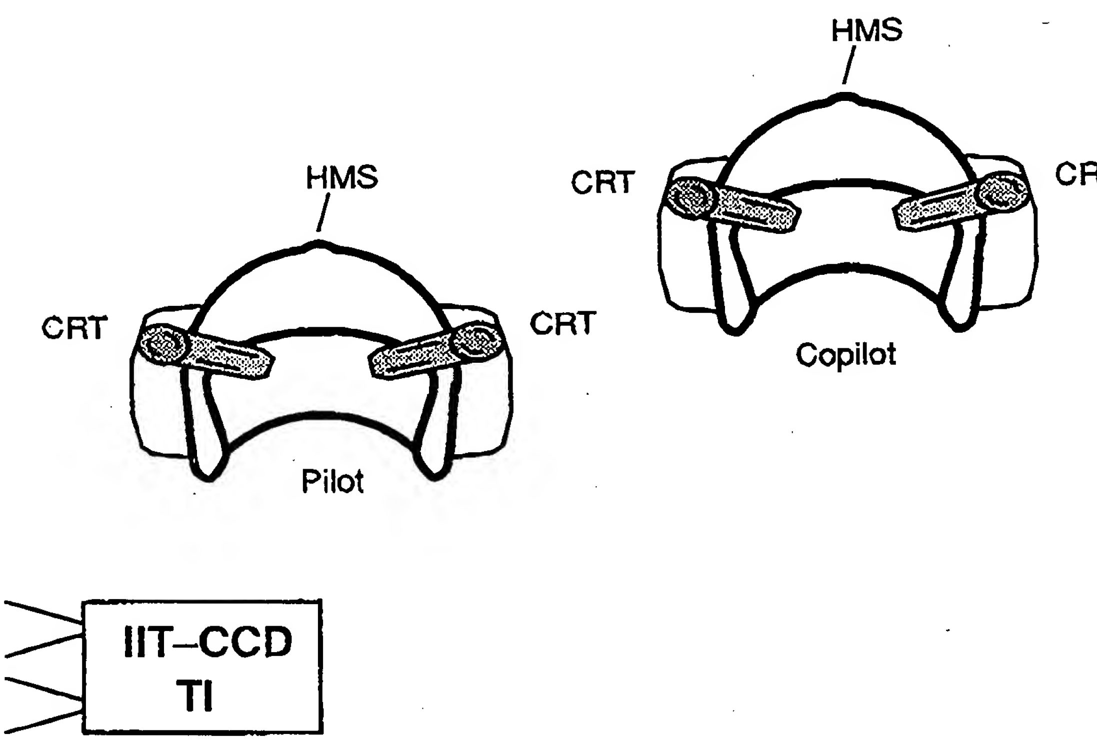

Fig. 19 Nose solution with IIT–CCD and IH only 2 CRT, sensor fusion possible, no sensor (TI and IIT–CCD) parallax and reduced flight safety.

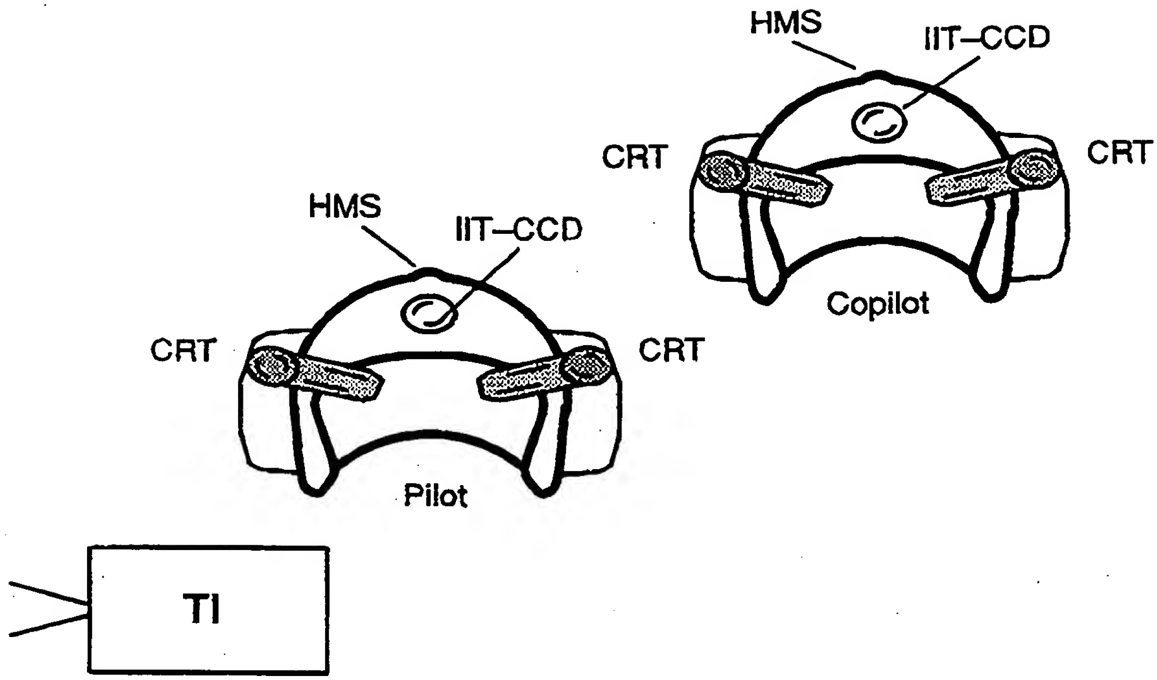

Fig. 20 Improved IH with 2 CRT and one IIT–CCD sensor on helmet, no problems of optical combiner/brightness between TI and IIT.

4. CONCLUSION

The helicopter flight trials and laboratory tests are carried out to gather experience of operation with state of the art IH equipment before deciding on the final configuration. The extensive trials showed that there is no substitute for flight trials, e.g. laboratory and simulator tests only, to completely understand an IH for day and night flight capability. The difficult human engineering aspects have to be evaluated with functional IH models to find the necessary improvements.

The work of this paper is partly a result from a HMS measurement campaign on BK 117, visionic lab tests and troop flight trials with PAH 1. These programmes were launched by "Bundesamt für Wehrtechnik und Beschaffung" (BWB) and "Bundes Ministerium für Verteidigung" (BMVg, German Ministry of Defence).

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